TOWARD OBJECTIVE MEAT QUALITY EVALUATION: MULTISPECTRAL MACHINE VISION APPROACH

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INTRODUCTION

Meat color and intramuscular fat (IMF) evaluation can involve subjective and objective assessment methods. Subjective assessment often employs the use of the National Pork Producers Council (NPPC) color standards, or similar subjective measurement methods. Objective measurement with devices like the Minolta Chroma Meter provides a single value but doesn't distinguish between meat and fat accurately. The primary objective of this work was to investigate the possibility of generating a continuous score for quantifying whole–slice meat quality (color and marbling) using hyperspectral imaging, aiming for high quality data for a pig breeding program.

MATERIALS AND METHODS

Pork *longissimus dorsi* muscle (fresh [n=22] and frozen [n=41]) and fresh ham portions (*gluteus medius* [n=20] and *gluteus profundus* [n=20]) were collected. The hyperspectral camera employed for capturing Hyperspectral Images (HSI) is the Specim IQ, facilitated by Specim's push-broom technology, and a standard imaging resolution (512x512 pixels). Two halogen light sources (D65) were used from a 45-degree angle, and the camera was placed perpendicular to the sample at a height of approximately 20 cm. A reference target with a known reflectance was placed for calculating the incident light intensities, which was later used for calculating the reflectance. Using these settings, HSI were captured on all samples, with each HSI dataset having 204 bands with a spectral resolution of 2.9 nm, and a wavelength range extending from 400 nm to 1000 nm. Each slice was also evaluated for whole number NPPC color and marbling values, determined by a trained expert, and a corresponding decimal NPPC value ($NPPC_d$). These parameters served as the foundational elements for the comprehensive evaluation of pork meat quality in this study. The data distribution is illustrated in Figure 1 below.

Data analysis

The objective is to extract a meat-only spectral signature for each meat slice. As observed, the meat slice is composed of roughly three spatial regions: meat, subcutaneous fat, and IMF. Observations of the spectral signatures of these three regions, within the same slice and throughout different slices, confirm that a different spectral signature exists between these three regions. More specifically, variability in the level of the spectral signature, but not of the signature itself, was observed (Figure 1).

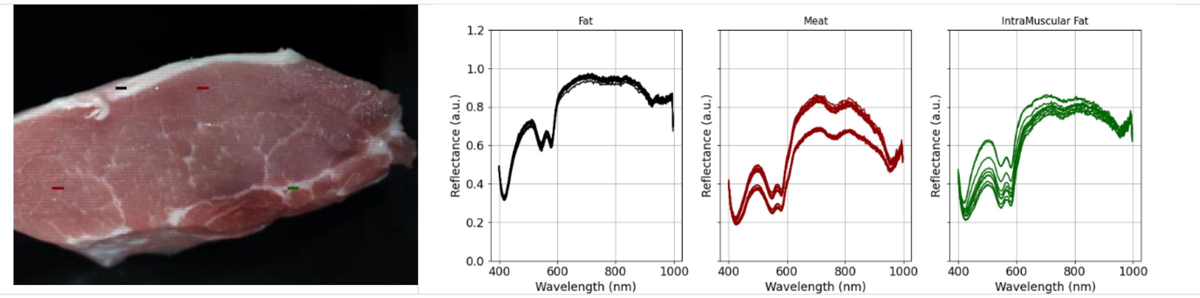

Figure 1. Spectral signatures (right) of manually delineated regions within one pork slices (loin, left, RGB representation). Three regions covering subcutaneous fat (black), meat (red) and intramuscular fat (green) were extracted.

Based on this observation, a fat extraction method was implemented based on the hypothesis of spectral invariance within each region. Two spectral regions, defined by lower and higher wavelength boundaries, were defined as the “low wavelength band” and “high wavelength band”. For each pixel of the meat slice, the spectral response was averaged within these two regions. The ratio between these two spectral regions was then computed for each pixel: closer to identity for pixels with a "fat" spectral signature, and higher for pixels with a "meat" spectral signature. Finally, a simple threshold, empirically set to 2, allowed to generate pixel masks for the fat regions (<=2) and meat regions (>2).

As our objective is to quantify a subjective visual perception of meat quality, the analysis was constrained to wavelengths in visible spectra, from 400nm to 850nm, ended up in 154 wavelengths.

Statistics

A spectral signature was generated for the 103 pig meat slices (Figure 2). Based on this spectral signature, a simple linear regression model was fitted where the explanatory variables were the 154 bands and the NPPC or $NPPC_d$ were the variables to explain.

As the wavelength bands are quite narrow, there is high correlation between variables. In this work, the dimension was reduced from 154 variables to 3 variables. To find these variables a brute force technique was used: a linear model was fitted to each 3-wavelength combination, and the combination giving the highest goodness-of-fit was considered the optimal choice of bands. A Leave One Out (LOO) validation scheme was implemented to measure the quality of the model. In such scheme, one model is fitted using all but one slice in the dataset. The model obtained is then used to predict the slice that was not used in the fitting step. Once done for all data points, the metrics such as goodness-of-fit (R^2) and mean absolute percentage error (MAPE) were calculated between the predictions and the variables to explain (NPPC or $NPPC_d$).

RESULTS AND DISCUSSION

The 3 bands found to give the best results are 576.5nm, 723.5nm and 782.4nm. Figure 2 (middle) shows the R^2 obtained with all the 3-wavelength combinations, in the order tested and sorted from best to worse.

Using these three bands, the predicted $NPPC_d$ are plotted against the true $NPPC_d$ in Figure 2 (right). The group information was added to the drawing to show that there is no difference in prediction between the groups. The correlation between predicted and true is R^2=0.87. This gives confidence that the spectral signatures contain enough information to represent the meat quality as scored by meat quality experts.

Hyperspectral cameras enable imaging of narrow spectral bands across a continuous spectrum range, producing spectra for all pixels in the scene. This novel method provides a machine vision-based assessment of meat color that reflects meat quality as perceived by consumers.

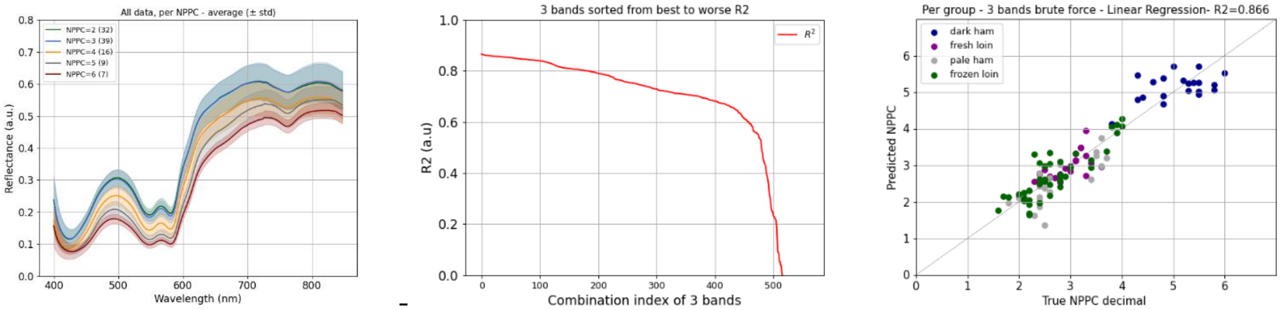

Figure 2. Left: All 103 spectral signatures per NPPC, represented with the mean and std of each group. Middle: Validation metrics (R^2) obtained with all the combinations of 3 bands, ordered from best to worse. Right: Predicted NPPC (y-axis) plotted against the true $NPPC_d$ (x-axis), optimal three bands.

CONCLUSION

The project has demonstrated the feasibility of developing a method for evaluating meat quality using non-invasive multispectral machine vision, based on meat color and marbling measured with a hyperspectral camera. The proposed method demonstrates excellent segmentation capability and provides an objective measure of fat and meat color akin to human visual perception.